Implementation of Digital System for Generation of Colored Noise using Pseudo Random Sequence with Smooth Spectrum

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Abstract— The noise generation is significant for test and validation of any electronic circuits such as filters, amplifiers, up- converter, down-converter, Modulators and demodulators (MODEM's) , communication channel, etc. In this paper, the possibility of using a 48bit linear feedback shift register(LFSR) which generates a sequence of random numbers, filtered with a finite impulse response filter(FIR) , for the generation of a programmable colored noise is explored. The FIR Filter is simulated on Integrated Software Environment (ISE) Simulator and synthesized using Xilinx ISE 14.7 with the help of Virtex- 5 Field Programmable Gate Array (FPGA).The contribution of this research work is to design an efficient digital system for generation of colored noise with improved spectral characteristics.

Keywords— LFSR's, Colored noise, FIR filter design, (FPGAs), Xilinx ISE 14.7, MATLAB (FDA Tool), random number generation.

I. INTRODUCTION

In communication system, noise is mostly modeled as white noise. White noise is a purely random noise that has an impulse autocorrelation function and a flat power spectrum. Theoretically white noise contains all frequencies in equal proportion. Over the total repetition spectrum, when the power spectral density of the noise is not reliable, then that type of noise is called as a colored noise. The white noise is crossed over a FIR bandpass filter to produce a colored noise. This signal finds applications in biomedical engineering, circuit theory, communication systems, computers, electro-acoustics, geosciences, physical electronics, instrumentation and other fields. The noise signal can be used as a broadband random signal or a test signal. The application of random noise is useful in electronic counter-measures, simulation of random quantities and generation of random numbers.

The white noise is passed through a filter to generate a colored noise[1]. This paper proposes a filtering circuit and an algorithm to design the programmable colored noise generator that produces an arbitrary colored electrical noise .The system proposed in [1]improves the performance in terms of noise bandwidth, power dissipation and logic resource occupation. This paper[2] presents for the novel method for generating the synthetic jitter patterns from colored noise with Gaussian distribution. Filtering generated colored noise do not have a Gaussian distribution. The minimum necessary power of the white noise floor is automatically computed, through an algorithm that increases or decreases the white noise power until Gaussian distribution properties for the generated pattern are achieved.

Utilizing a single bit pseudo random sequence, filtered with a FIR filter has the probability to produce a noise with chosen PSD and is presented in [3]. For producing noise, the authors have preferred the Nyquist bandwidth and completed the process of interpolation and upsampling. The experimental results indicate its suitability for real time applications and user can easily control spectral features of the generated noise. This technique uses less resources, when implemented on a Field Programmable Gate Array (FPGA) but has an impact on the dynamic range of the sequence . For generating the random waveforms, the authors in [4] and [6] , have utilized the advantage of an analog generator as a noise source. The circuit proposed is characterized by structured spectral patterns. These generated noise sources are required in several applications which include measurement of the frequency response of linear systems, measurement of noise figures andthe functional test of microwave and optoelectronic links[4].

For an effective scheme , the investigators [5] have targeted on the dimensions that are infinite for the production of a noise series. With the obtained laboratory results , the authors have concluded that the range of frequency up to maximum of 120MHz of the produced noise can be chosen. The different methods of hardware Gaussian noise generation are described in [7],[8],[9]. The hardware Gaussian noise generator designed using Box-Muller method can be used for unique national research facility that carries out robotic space and Earth science missions. The Wallace method can be used for generating noise at different channels such as Rayleigh, Ricean and Nakagami-m channels[9].The solutions proposed in the above cited literature do not allow the generation of arbitrarily colored noise. The authors in [10] discuss techniques for generating colored-noise sequences which simulate processes with a given spectral density. MATLAB routines based on the fast fractional difference algorithm are presented. The result shows that the generalized Gauss Markov (GGM) approximation has a potential for alleviating the red-noise leakage in the PSD estimates. Power spectral density (PSD) show that the algorithms are accurate and efficient, and can be easily implemented for stationary noise. From the literature review, it was concluded that though different methods were used to generate colored noise, the performance of a system is generally controlled by the performance of the multiplier. Furthermore, multiplier is normally the most area consuming element in the system. Therefore, optimizing its speed and area are vital design factors to implement a digital system for generation of colored noise signal.

The principal contribution of this research work is to design an efficient digital system for generation of colored noise with improved spectral characteristics, enhanced dynamic range and less occupied area. It is also aimed to give an easy simulation approach with a more general form that can be applicable for various types of colored noises. Here, a 48-bit LFSR with maximum length polynomial which generates random numbers is designed, and the generated white noise is filtered with a 64 tap finite impulse response (FIR) bandpass filter to extract the colored noise with desired spectral characteristics and ensure more stopband attenuation and less ripple.

The LFSR[11] approach offers the possibility of implementing multiple uncorrelated sources with very small area overhead. The drawback of word length limitation of output signal is addressed by increasing the length of the shift register. This work also involves the design of 64 taps for improving the accuracy of the filter. The 64 tap finite impulse-response (FIR) bandpass filter is designed in MATLAB using Hamming window method and the same filter is simulated and synthesized on Xilinx ISE 14.7 on Virtex-5 FPGA board to target the device XC5VLX330 . System analysis and simulated results show that without significant increase in circuit size it is possible to improve the quality of the output digital sequence. The remaining part of the paper is explained as follows. Section II gives the detailed explanation for the block diagram of the Generation of Colored Noise System. Section 2.1 describes the process for generating white noise. Section 2.2 briefly explains the FIR Filter design. The remaining section describes the circuit implementation and the work is concluded with Section IV.

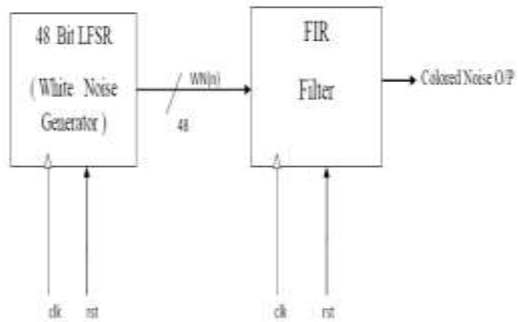

Figure1. Block diagram for the Generation of Colored Noise System

II. GENERATION OF COLORED NOISE SYSTEM

The block diagram for the generation of colored noise is shown in above figure1. The circuit uses a 48 bit LFSR that generates a white noise sequence of random numbers with a good frequency response and the output is filtered with a bandpass filter to generate the colored noise. The 48 bit LFSR produces the random numbers with a white power spectral density (PSD). The maximum frequency of the white noise is 25KHz.The frequency response of white noise is determined by taking the FFT of the generated random numbers. The filter is designed using 32 bit Baugh Wooley Multiplier , 64 bit ternary adder, filter coefficients h(n) and delay elements. The coefficients of the filter are obtained by designing the bandpass filter in MATLAB FDA (Filter Design Analysis) toolbox.

2.1 Generation of White Noise

For the production of white noise, a pseudorandom sequence with smooth spectrum is carried out and the chosen PSD is given to the digital FIR to set up the noise series. The random numbers are produced using a 48 Bit Linear Feedback Shift Register which requires 48 D-Flip-flops and some XOR gates. Each D-Flip-flop uses asynchronous reset which is independent of clock. Here, D flip-flops are used as registers and Q is the output of the each register. Flip-flops operate as standard shift registers and generate repetitive sequences of random values. The outputs of some of the flip flops in the shift register are feedback as input to a XOR gate and the output of XOR gate is the input to the first flip flop in the shift register. The LFSR generates a random sequence of length (2n- 1) states . The random numbers repeat itself after (2n- 1) clock cycles (where n is the number of bits in LFSR).The maximum length of an LFSR sequence is (2n- 1) which generates the random periodic sequence. The polynomial equation for 48 bit LFSR generates $2^{48} - 1 = 281{,}474{,}976{,}710{,}655$ random numbers. This random numbers produces white noise. Initial value of LFSR is called as seed value. The taps values determine the polynomial equation and gives the repetitive sequences. The choice of taps determines the number of values in a given sequence before the sequence repeats. Its timing simulation waveform is shown in figure2. The power spectral density spectrum is displayed in figure 3 and figure 4.

Figure2. Simulation waveform of 48 Bit LFSR
(Random Number generation)

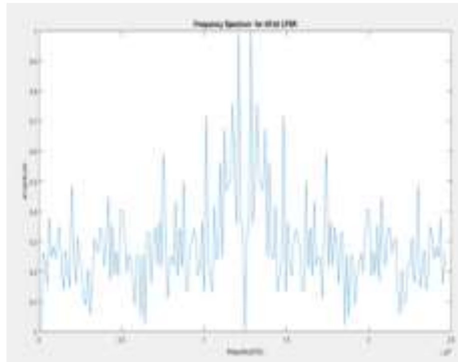

Figure3. Frequency spectrum for White Noise

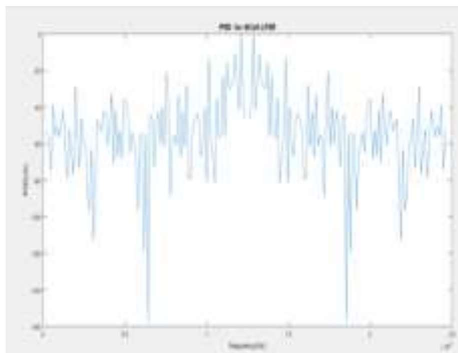

Figure4. PSD spectrum for White Noise

2.2 FIR Filter Design Flow

The white noise is moved through a digital FIR bandpass filter to produced a colored noise. The recommended FIR bandpass filter is coded in VHDL language with MATLAB R2015A (for the generation of coefficients of filter) is explained in this section. Performance evaluation is done based on the implementation results obtained through Xilinx ISE tool. Bandpass filter is designed in MATLAB for sampling frequency of 500 KHz and Pass-band and stop-band frequency of 20Hz and 20KHz respectively. The coefficients are computed through the Hamming window technique. Coefficients of the filter are calculated using FDA (Filter Design and Analysis) toolbox in MATLAB R2015A and these coefficients are converted into binary numbers which are used for implementing the filter design. For designing of 64 tap FIR Bandpass Filter, 64 Bit Ternary adder and 32 bit Baugh Wooley Multiplier is required which exhibits less delay, low power dissipation and the area occupied is small as compared to other array multiplier. These blocks are designed in VHDL language and simulated in Xilinx environment. The structure of the 64 Tap FIR bandpass filter is shown in figure 5.

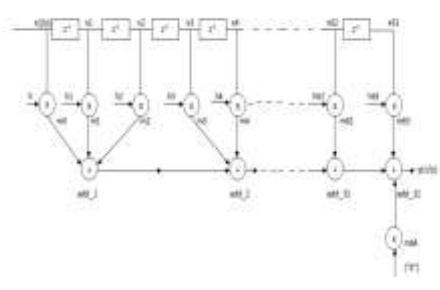

Figure5. Block Diagram of the FIR filter

The "Baugh Wooley Multiplier" and the " ternary adder tree" are depicted in Figure6 and Figure7 respectively.

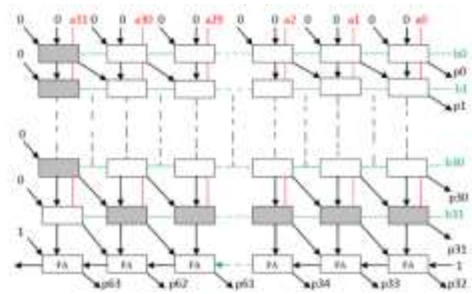

Figure6. Block diagram of 32 Bit Baugh Wooley Multiplier

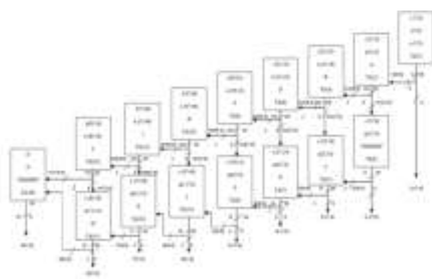

Figure7. Block diagram of 64 Bit Ternary adder

The output of a filter y[n] to an input response of x[n] is determined by the convolution function

$$y[n] = h[n] * x[n] \qquad - (1)$$

where, x(n) is the input sequence, y(n) is the output sequence, h(n) is called as the coefficients of the filter. The FIR filter of length M with input x(n) and output y(n) is described by the difference Equation -

$$y(n) = h0x(n) + h1x(n-1) + \ldots\ldots.. + hMx(n-M-1) \qquad - (2)$$

$$y(n) = \sum_{k=0}^{M-1} hkx(n-k) \qquad -(3)$$

where {hk} is the set of filter coefficients.

The filter order is 63 and length of the filter is 64. The tap blocks are also called as filter coefficients. The FIR Bandpass Filter is designed using hamming window so as to obtain the filter coefficients, magnitude as well as phase response of FIR filter. To reduce area, delay and the design complexity of the filter, symmetric coefficients are taken. The magnitude response and phase response are shown in figure 8(a) and 8(b).

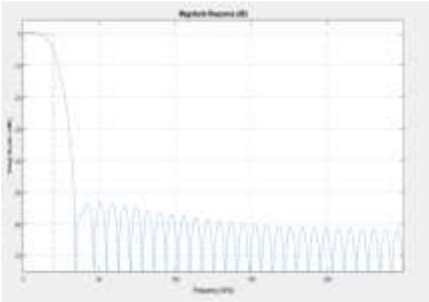

Figure8(a). Magnitude response of FIR Filter

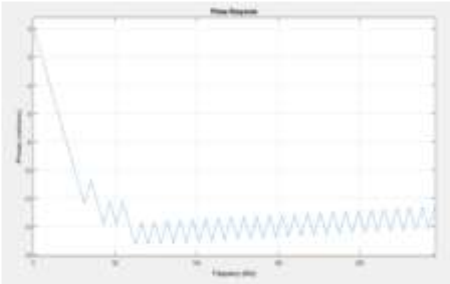

Figure8(b). Phase response of FIR Filter

III. RESULTS

The coefficients are put in FIR filter testbench. The maximum operating frequency of the designed FIR filter is 18.502 MHz and the minimum period is 54.049 ns. After simulation of the digital system designed to generate the colored noise, it is synthesized and the report is as given in table- I. The target device is xc5vlx330-1-ff1760.

Table - I : Device Utilization Summary

Slice Logic Utilization	**Used**	**Available**	**Utilization**
Number of Slice Registers	2094	207360	1%
Number of Slice LUTs	78682	207360	37%
Number used as Logic	78682	207360	37%
Slice Logic Distribution			
Number with an unused Flip Flop	78604	80698	97%
Number with an unused LUT	2016	80698	2%
Number of fully used LUT-FF pairs	78	80698	0%
IO Utilization			
Number of bonded IOBs	100	1200	8%

IV. CONCLUSION

This paper implements a FPGA based digital circuit using LFSR and FIR filter to generate colored electrical noise. The colored noise is generated using white noise signal followed by FIR filter. The generated white noise signal uses a 48 Bit LFSR technique. To produce colored noise, the probability of using a 48 bit white noise source with fixed power spectral density is labeled in this paper. While designing the FIR bandpass filter, a Ternary adder is used as it reduces the combinational logic. Synthesis results indicate the device Virtex-5 utilization for input-output resources. The presented generator is suitable for applications in which colored noise is required with fixed power spectral density. Use of Baugh Wooley Multiplier leads to less occupied area and delay .

V . REFERENCES

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